MULTIPLE PURPOSE PROJECT

NARRAGANSETT PIER

RHODE ISLAND

DESIGN MEMORANDUM NO. 1

HYDROLOGY AND HYDRAULICS

U.S. ARMY ENGINEER DIVISION, NEW ENGLAND
CORPS OF ENGINEERS   WALTHAM, MASS.

SEPTEMBER 1965

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U. S. ARMY ENGINEER DIVISION, NEW ENGLAND
CORPS OF ENGINEERS
424 TRAPELO ROAD
WALTHAM MASS 02154

ADDRESS REPLY TO:
DIVISION ENGINEER

REFER TO FILE NO

NEDED-R

17 September 1965

SUBJECT: Multiple Purpose Project, Narragansett Pier, Rhode Island, Design Memorandum No. 1, Hydrology and Hydraulics

TO: Chief of Engineers
ATTN: ENGCW-E

There is submitted herewith for review and approval Design Memorandum No. 1, Hydrology and Hydraulics for the Multiple Purpose Project, Narragansett Pier, Rhode Island in accordance with EM 1110-2-1150.

FOR THE DIVISION ENGINEER:

John Wm Leslie

JOHN WM. LESLIE
Chief, Engineering Division

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MULTIPLE PURPOSE PROJECT

NARRAGANSETT PIER
RHODE ISLAND

DESIGN MEMORANDUM NO. 1

DESIGN MEMORANDA INDEX

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1	Hydrology and Hydraulics	17 Sept 1965	
2	General Design (Including Site Geology, Embankments and Real Estate)		
4 ~~3~~	Walls and Concrete Apron		
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MULTIPLE-PURPOSE PROJECT
NARRAGANSETT PIER
NARRAGANSETT, RHODE ISLAND

DESIGN MEMORANDUM NO. 1

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DESIGN MEMORANDUM NO. 1

HYDROLOGY AND HYDRAULICS

INTRODUCTION

1. PURPOSE

This memorandum describes the hydrologic and hydraulic criteria applicable to the design of structures included in the Narragansett Pier Multiple-Purpose Project. Part I - Hydrology, includes sections on climatology, streamflow, derivation of design floods, regulation procedures and design of the land dike culvert. Part II - Tidal Hydraulics, includes sections on experienced tidal flood heights and the frequency of tidal flooding, and the determination of design tidal flood levels and associated wave heights, wave runup and overtopping.

2. DESCRIPTION

Narragansett Pier, a summer resort area in the town of Narragansett, Rhode Island is located about 30 miles south of Providence near the west entrance to Narragansett Bay. The shore area of Narragansett Pier consists of a sand beach approximately 6,000 feet long on the north and a rocky area about 3,500 feet long on the south. The sand beach is bounded on the north by the Narrow River and on the south by an eroding headland. The rocky area on the south is backed up by a concrete seawall and Ocean Road, a scenic highway leading to Point Judith. Narrow River is a tidal inlet to the Pettaquamscutt River and Cove north of the Pier. The river provides water access to the Atlantic Ocean for the rapidly expanding summer population along the river.

3. PROBLEMS

The problems at Narragansett Pier which the project is designed to solve are:

a. Inundation and wave damage by hurricanes. Damages amounted to $2,240,000 in hurricane "Carol" 31 August 1954, in the Narragansett Pier, Pettaquamscutt Cove and Narrow River areas.

b. Shore and beach erosion. Over the years the Narragansett Pier area has suffered from severe and continuing erosion of the shore and beach.

c. Navigation. A local boat anchorage and harbor of refuge are needed to serve recreational boating and fishing. Narrow River in its present condition is too hazardous because of rocks, currents and shoaling.

4. PLAN OF IMPROVEMENT

The recommended multiple-purpose project (hurricane and beach protection and navigation) would raise and widen the natural beaches of Narragansett Pier above hurricane flood levels with sand fill to dissipate the energy of great storm waves; construct groins, a low concrete backwall, a land dike across the outlet of Little Neck Pond and a sand barrier on Little Neck Point. A harbor of refuge and anchorage would be provided in the Narrow River. A location map and general plan of the area are given on plate 1-1 and pertinent details are shown on plate 1-2.

PART I - HYDROLOGY

CLIMATOLOGY

5. CLIMATE

The Narragansett Pier area has a temperate humid climate marked by four distinct seasons which are characteristic of its latitude and of New England. Since the area is in the zone of interaction of tropical and arctic air masses, the weather is changeable - hot and cold, dry and wet. Owing to the moderating influence of the nearby Atlantic Ocean and particularly to the variable easterly movement of high and low pressure systems across the area, extremes of either hot or cold weather are usually of short duration. In the winter, coastal storms frequently bring rainfall in contrast to snow in the more northerly areas of New England. In the summer, cooling relief from hot, humid weather is provided by easterly and southerly sea breezes, thunderstorms from the west and cool air from the north. The prevailing winds are northwesterly in the winter and southwesterly in the summer. High winds, heavy rainfall and abnormally high tides may occur during any month of the year. Hurricanes and tropical storms occur during the months of August, September and October.

6. CLIMATOLOGICAL RECORDS

A U. S. Weather Bureau Station has been maintained at Kingston, Rhode Island approximately 5 miles northwest of Narragansett Pier since 1889. The records are considered to be representative of the climate at Narragansett Pier.

7. TEMPERATURE AND PRECIPITATION

The average annual temperature at Narragansett Pier, based on Kingston records, is 48° F. The coldest months, January and February, have mean temperatures of 28° F. and the warmest month, July, has a mean temperature of 69° F. The lowest temperature was -23° F. on 11 January 1942 and the highest 99° F. on 9 August 1949.

The annual precipitation has ranged from a minimum of 32 inches in 1943 to a maximum of 72 in 1898. The average annual precipitation is 48 inches, distributed rather uniformly throughout the year. Average monthly precipitation varies between 3.2 inches (June and July) and 4.5 inches (March). Extremes of monthly precipitation have ranged from 0.04 inch (June 1949) to 13.56 inches (August 1952).

Monthly temperature and precipitation records are summarized in Table 1-1. Snowfall occurs from November to April, averaging 33 inches per year.

8. STORM RAINFALL

A study of storm rainfall and storm tides at Narragansett Pier indicates that the largest rainfalls have not been associated with hurricane surges. In August 1924, an extremely heavy rainfall of 6.9 inches in 24 hours was measured at Kingston, Rhode Island. The hurricane center passed southeast of Nantucket and did not cross the southern shoreline of New England. Tides were above normal causing some flooding. Rainfall during the hurricanes of September 1938 and August 1954 which caused the highest tidal stages, amounted to 1.3 and 2.9 inches, respectively. Table 1-2 presents a summary of storm rainfalls that have occurred at Narragansett Pier as indicated by Kingston records.

TABLE 1-1

MONTHLY TEMPERATURE AND PRECIPITATION
KINGSTON, RHODE ISLAND
(Elevation 100 feet msl)

Month	Temperature in Degrees F.			Precipitation in Inches		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum
January	28.0	63	-23 (2)	4.50	11.43	0.83
February	28.0	64	-22	3.99	9.44	0.67
March	35.7	82	- 4	4.51	9.67	0.23
April	45.0	85	8	4.35	9.70	0.72
May	55.1	93	25	3.81	8.95	0.67
June	63.9	96	30	3.20	7.42	0.04 (4)
July	69.4	98	38	3.20	11.75	0.43
August	68.1	99 (1)	33	4.43	13.56 (3)	0.79
September	62.0	95	25	3.73	12.66	0.35
October	52.1	87	13	3.83	12.05	0.27
November	41.5	76	4	4.42	10.25	0.41
December	31.0	65	-17	4.36	11.59	0.83
ANNUAL	48.3	99 (1)	-23 (2)	48.33	72.22 (5)	31.76 (6)

(1) 9 Aug 1949
(2) 11 Jan 1942
(3) 1952
(4) 1949
(5) 1898
(6) 1943

TABLE 1-2

STORM RAINFALL AT KINGSTON, RHODE ISLAND
AND MAXIMUM TIDAL ELEVATIONS AT
NARRAGANSETT PIER, RHODE ISLAND

Hurricane or Storm	Maximum 1-Day Rainfall (inches)	Maximum Tidal Elevation (feet msl)
Aug 1924	6.9	(a)
Sept 1932	6.2	(b)
Sept 1938	1.3	13.8
Sept 1944	2.4	9.0
Aug 1954 (Carol)	2.9	12.8
Sept 1954 (Edna)	5.5	(b)
Aug 1955 (Connie)	5.3	(b)
Aug 1955 (Diane)	2.2	(b)
Oct 1955	3.1	6.7
Sept 1960	1.6	7.8
Sept 1961	6.5	6.9

(a) "Cottages and stores - flooded"
(b) Less than 6.0

9. RAINFALL FREQUENCIES

Rainfall amounts for various frequencies and durations were derived from maps in Weather Bureau Technical Paper No. 36, "Rainfall Frequency Atlas of the United States," and are shown in Table 1-3.

TABLE 1-3

RAINFALL FREQUENCY
PRECIPITATION IN INCHES

Duration in Hours	Exceedence Interval in Years			
	10	25	50	100
1	2.05	2.3	2.6	3.0
2	2.55	2.9	3.3	3.7
3	2.85	3.3	3.7	4.2
6	3.45	4.0	4.5	5.0
12	4.15	4.9	5.5	6.0
24	4.95	5.8	6.5	7.2

INTERIOR DRAINAGE

10. GENERAL

Interior drainage facilities consist of two existing ponds, connected in series, for the temporary ponding of interior runoff and a gravity outlet through the land dike. The upper pond, Lake Canonchet, has a drainage area of 200 acres. Its outlet into the lower pond, Little Neck Pond, is a 60-inch diameter culvert. Little Neck Pond drains an additional 75 acres. Its outlet is a small creek which flows northwest into Pettaquamscutt Cove. A culvert will be constructed through the land dike, and the creek which drains Little Neck Pond will be improved.

11. RUNOFF

Estimates of runoff were based on rainfall frequency data and an assumed loss rate of 0.1 inch per hour. A 10-year, 6-hour rainfall of 3.45 inches would produce a runoff of 2.85 inches. A 50-year, 12-hour rainfall of 5.5 inches would produce a runoff of 4.3 inches.

12. PONDING AREAS AND CAPACITIES

During hurricanes and storms when drainage will be blocked by storm tides and the gate in the closure dike outlet will be closed, the runoff will pond in Lake Canonchet and Little Neck Pond. At elevation 7.2, Lake Canonchet begins to flow across the road separating the two ponds. Separate curves of area and capacity were prepared for the two ponds up to this elevation and are shown on plate 1-3. Drainage areas and ponding capacities at elevation 7.0 are summarized in the following tabulation:

	Drainage Area (acres)	Ponding Capacity (Elevation +7.0)	
		Acre-Feet	Inches
Lake Canonchet	200	31.1	1.9
Little Neck Pond	75*	58.7	9.4
Total	275	89.8	3.9

* Increment

13. DESIGN CRITERIA

Interior drainage facilities are designed to meet two situations. First, they must keep out the hurricane and storm tides, temporarily store the runoff from the area inclosed by the dikes, and discharge the stored runoff following recession of the abnormal tide. The design rainfall selected for this condition was a 10-year, 6-hour rainfall. Second, the facilities must discharge the runoff from storms occurring coincident with tides 2 feet above normal without causing inundation of residential or commercial areas. The selected design rainfall for this condition was a 50-year, 12-hour rainfall with a critical sequence of hourly rainfall amounts. The drainage facilities are also designed to maintain the present normal level of the interior ponds.

14. PONDING ELEVATIONS

For a 10-year, 6-hour rainfall coincident with the design hurricane tide, the runoff would be 2.85 inches or 65 acre-feet from the total 275-acre drainage area. Assuming initial elevations of 3.0 feet msl, the 2 ponds would fill to elevation 6.4 feet. A study of the hurricane of 21 September 1961 (Esther) indicates that the gates would probably have been closed for about 8 hours during which the rainfall was 3.14 inches. The runoff would have been 2.34 inches or 53.6 acre-feet. The 2 ponds would have filled to elevation 5.8 feet.

15. PUMPING STATION

A pumping station is not considered necessary at Narragansett Pier because the ponding areas are adequate to pond the runoff with only minor inundation damage.

16. GRAVITY OUTLET

A gravity outlet, as shown on plate 1-1, will be provided through the landward dike. The invert elevation at the downstream end of the culvert will be -1.0 foot msl and the bottom slope will be 0.5 percent. A sluice gate will be provided to close the outlet during hurricane and storm tides. A low weir at elevation 3.0 feet msl, upstream from the culvert entrance, will maintain the levels of Little Neck Pond and Lake Canonchet. A stoplog opening 4 feet wide will be provided in the weir. The gravity outlet is designed to pass the runoff from a critical sequence of 50-year, 12-hour rainfall with high and low tides running 2 feet above normal. Under these conditions Little Neck Pond will reach a maximum elevation less than 6.0 feet msl. The size of the gravity outlet has little effect upon the maximum stage of the upper pond, Lake Canonchet. Assuming two 60-inch diameter pipes between the ponds, as described in the following paragraph, the maximum stages reached by Lake Canonchet would be as follows:

Gravity Outlet	Elevation (feet msl)
4 x 4 foot culvert with 24-foot weir	7.0
5 x 5 foot culvert with 40-foot weir	6.9

A rating curve for the 5 x 5 foot culvert and a graph of a flood routing are shown on plate 1-3. Since the delay of runoff by overland flow would be small it was neglected in the routing in order to simplify the computations.

17. CULVERT BETWEEN PONDS

The 60-inch concrete pipe culvert, connecting Lake Canonchet and Little Neck Pond, is half-filled with sand and gravel. It will be cleaned out to restore its full capacity. The culvert is 50 feet long with bell ends both upstream and downstream. Based on the assumed loss rate of 0.1 inch per hour, the culvert is inadequate to pass the runoff from a 50-year, 12-hour rainfall, and the rise in pond level would result in shallow inundation of the business area and flow over the road at the culvert. In order to avoid the shallow inundation during the 50-year storm, an additional pipe of the same size, parallel to the existing pipe, would be required. It is considered that the minor damage caused by the infrequent inundation, which might also be experienced under present conditions, does not justify the cost of a second culvert. A rating curve for the culvert is shown on plate 1-3.

PART II - TIDAL HYDRAULICS

NORMAL CONDITIONS

18. NORMAL TIDES

Two high and two low tides occur each lunar day at Narragansett Pier. The mean tide range is 3.2 feet, with mean low water 1.7 feet below mean sea level and mean high water 1.5 feet above mean sea level. Spring tides have an average range of 4.0 feet and a maximum range of about 6 feet. A maximum spring tide will reach an elevation 4.7 feet above mean low water (1.5 feet above mean high water). The time interval for a complete tidal cycle averages about 12 hours and 25 minutes. Tidal predictions are given for 19 locations in the Narragansett Bay area in the yearly publication of the U. S. Department of Commerce, Coast & Geodetic Survey, entitled: "Tide Tables, East Coast, North and South America." Tidal data for Narragansett Pier are summarized in Table 1-4.

TABLE 1-4

NORMAL TIDES - NARRAGANSETT PIER, NARRAGANSETT, RHODE ISLAND

		Elevation in Feet Related to MSL
Mean Tide Range in Feet	3.2	
Mean High Water		1.5
Mean Low Water		-1.7
Average Spring Tide Range in Feet	4.0	
Mean Spring High Water		2.2
Predicted Maximum Spring High Water		3.0
Estimated Minimum Low Water		-4.2

The tidal range of the Pettaquamscutt River varies with the conditions of shoaling at the inlet to the Narrows. The mean tidal range varies from the ocean to the Pettaquamscutt River as follows:

Ocean	3.2 feet
The Narrows	2.0 feet
The Pettaquamscutt River and Cove	1.5 feet

Strong variable currents exist at the Narrows where the river is about 150 feet wide at mean high water.

19. RECORDING TIDE GAGES IN THE NARRAGANSETT BAY AREA

Data on the 12 recording tide gages in the Narragansett Bay area are given in Table 1-5. Six of these gages are presently in operation and six have recently been removed from the area as indicated in the table. Locations of these gages are shown on plate 1-4. The gage identification numbers, as indicated on this plate, correspond to the item numbers as given in Table 1-5.

20. FACTORS INFLUENCING TIDES

Tides are subject to meteorological influences such as changes in atmospheric pressure and strong winds, besides the normal gravitational effects of the sun and moon. A drop in barometric pressure of 1 inch of mercury will cause about a 1-foot rise in water levels. During coastal storms tide levels often build up several feet above the predicted normal elevations.

EXPERIENCED HURRICANE AND SEVERE STORM TIDAL FLOODING

21. RECENT HURRICANES AND SEVERE STORMS

In the last 26 years the Narragansett Bay area has been subjected to tidal flooding from 3 major hurricanes, severe flooding from the hurricane of 21 September 1938 and from hurricane "Carol" 31 August 1954 and moderate flooding from the hurricane of 14 September 1944. The 1938 and 1954 hurricanes followed paths 70 and 30 miles, respectively, west of Narragansett Pier, thus the pier was in the sector of the strongest and most damaging hurricane winds and where the storm surge was the highest. The center of the 1944 hurricane passed directly over the Pier. The tracks of selected major hurricanes are shown on plate 1-5. Observed and predicted tidal heights at Narragansett Pier during the 3 major hurricanes of recent years are shown in Table 1-6. Minor tidal flooding has also occurred from a number of other hurricanes and severe storms in the past 26 years. Severe storms occurring mostly in the late fall, winter or early spring occasionally drive the water levels from 6.5 to 7.5 feet above mean sea level. Overtopping of the backshore beach in the vicinity of Ouida Street and the seawall along Beach Street often

TABLE 1-5

TIDE GAGE INVENTORY DATA - NARRAGANSETT BAY AREA

No.	Location	Type*	Period of Record	Agency
1	Block Island, R. I.	A,B,C	16 Nov 1955 - To Date	NED
1A	Narragansett, R. I.	A,B,C	4 Oct 1956 - To Date	NED
2	Newport, R. I.	A,B,C	10 Oct 1955 - 28 Apr 1965	NED
3	Little Compton, R. I.	A,B,C	27 Sept 1956 - 29 Sept 1964	NED
4	Narragansett, R. I.	A,B,C	10 Oct 1955 - 21 Apr 1965	NED
5	Newport, R. I.	A,B	10 Sept 1930 - To Date	USC&GS
6	North Kingstown, R. I. (Quonset Point)	A,B,C	17 Dec 1956 - To Date	NED
7	Portsmouth, R. I.	A,B,C	24 Oct 1955 - 24 Nov 1964	NED
8	Somerset, Mass.	A,B,C	24 Aug 1956 - 27 Apr 1965	NED
9	Cranston, R. I.	A,B,C	11 Oct 1955 - 30 Sept 1964	NED
10	Providence, R. I. (State Pier No. 1)	A,B	3 June 1938 - 23 June 1947 Aug 1956 - To Date	USC&GS
11	Providence, R. I. (Narragansett Electric Co.)	A,B	1956 - To Date	Narragansett Electric Co.

* Type of Gage: A - Recorder; B - Staff Gage; C - Maximum Level Gage

TABLE 1-6

TIDAL FLOOD DATA ON RECENT HURRICANES
NARRAGANSETT PIER, NARRAGANSETT, RHODE ISLAND

Hurricanes	Tidal Flood Crest: EST Time	Tidal Flood Crest: Elevation (feet msl)	Predicted Tide Elevation (feet msl)	Max. Surge Above Predicted Tide (feet)
21 Sept 1938	4:35 P.M.	13.8	2.3	11.5
14 Sept 1944	10:40 P.M.(1)	9.0(2)	-0.9	9.9
31 Aug 1954	10:25 A.M.	12.8	1.9	10.9

Hurricanes	Predicted Normal Tide: High Tide: EST Time	Predicted Normal Tide: High Tide: Elevation (feet msl)	Predicted Normal Tide: Low Tide: EST Time	Predicted Normal Tide: Low Tide: Elevation (feet msl)
21 Sept 1938	5:32 P.M.	2.5	11:05 A.M.	-2.0
14 and 15 Sept 1944	5:46 P.M.	2.0	12:23 A.M.	-1.4
31 Aug 1954	9:17 A.M.	2.3	2:58 P.M.	-1.5

(1) Estimated

(2) Based on tidal elevation data for Newport, Rhode Island, stage related to Narragansett Pier, Rhode Island

inundates Narragansett Pier streets during these storms, but the resulting damages are not normally serious. Detailed descriptions of the 3 major hurricanes of recent years are given in the following paragraphs.

22. HURRICANE OF 21 SEPTEMBER 1938

The damage caused by tidal flooding from this hurricane was the highest ever experienced in the Narragansett Bay area. An important factor in determining the height of flooding from a tidal surge is the stage of the normal tide at the time the hurricane surge arrives at the coast. The peak of the hurricane tide arrived at Narragansett Pier about 1 hour before the predicted normal high tide. Observed and predicted tidal heights at Narragansett Pier during this hurricane are shown in Table 1-6.

The maximum wind velocity recorded in New England during this hurricane was a gust of 186 miles per hour at the Blue Hills Observatory, Milton, Massachusetts located about 55 miles north of Narragansett Pier. The sustained 5-minute wind velocity during this hurricane, at this same location, was 121 miles per hour. Winds accompanying the 1938 hurricane were generally in excess of 75 miles per hour in the Narragansett Bay area. At Block Island, Rhode Island the wind attained a maximum recorded 5-minute sustained velocity of 82 miles per hour from the southeast and maximum gusts of 91 miles per hour before the anemometer was blown down. A maximum 5-minute wind velocity of 87 miles per hour from the southwest and gusts estimated at 125 miles per hour occurred at Providence, Rhode Island. The maximum gust and maximum 1-minute sustained velocity at Narragansett Pier were estimated at 100 and 90 miles per hour, respectively. The lowest barometric pressure ever recorded in New England was 28.04 inches at Hartford, Connecticut during this hurricane. Hartford is located about 70 miles northwest of Narragansett Pier. Minimum barometric pressures of 28.66 and 28.90 inches, respectively, were recorded at Block Island and Providence, Rhode Island. The forward speed of the hurricane near the Narragansett Bay area was about 55 knots (63 miles per hour). Hurricane tide curves at Narragansett Pier are shown on plate 1-6. The location map and hurricane flood levels based on observed high water marks from Point Judith, Rhode Island to the Rhode Island-Massachusetts state line are shown on plates 1-7 and 1-8.

23. HURRICANE OF 14 SEPTEMBER 1944

The peak of the hurricane tide arrived at Narragansett Pier about 1 hour and 45 minutes before the predicted normal low tide and therefore caused only a moderately high stage. Observed and predicted tidal heights at Narragansett Pier during this hurricane are shown in Table 1-6.

Wind velocities in the Narragansett Bay area during this hurricane were somewhat less than in the hurricane of 21 September 1938. At Block Island, Rhode Island a maximum 1-minute sustained wind velocity of 88 miles per hour from the southeast was recorded and maximum gusts in excess of 100 miles per hour were experienced. At the T. F. Green Airport, Hillsgrove, Rhode Island the maximum 1-minute sustained wind velocity was 49 miles per hour from the southeast and the maximum gust was 90 miles per hour. Minimum barometric pressures of 28.34 and 28.51 inches were recorded at Block Island and Providence, Rhode Island. The forward speed of the hurricane near the Narragansett Bay area was about 30 knots (34 miles per hour).

24. HURRICANE CAROL, 31 AUGUST 1954

The peak of the hurricane tide occurred at Narragansett Pier about 1 hour after the predicted normal high tide. Observed and predicted tidal heights at Narragansett Pier during this hurricane are shown in Table 1-6.

The wind attained a maximum 1-minute sustained velocity of 98 miles per hour from the southeast, with a maximum gust of 135 miles per hour at Block Island, Rhode Island. A maximum 1-minute sustained wind velocity of 90 miles per hour from the east-southeast, with a maximum gust of 105 miles per hour, occurred at the T. F. Green Airport, Hillsgrove, Rhode Island. A minimum barometric pressure of 28.50 inches was recorded at Block Island, Rhode Island and 28.79 inches at Providence, Rhode Island. The forward speed of the hurricane near the Narragansett Bay area was about 40 knots (46 miles per hour). Hurricane tide curves at Narragansett Pier are shown on plate 1-6. The location map and hurricane flood levels based on observed high water marks from Point Judith, Rhode Island to the Rhode Island-Massachusetts state line are shown on plates 1-7 and 1-8.

25. RECENT STORMS

Although hurricane tidal flooding has been recorded since 1635 in the Narragansett Bay area, records of elevations are meager until recent years. Chronological lists of hurricanes and severe storms that caused tidal flooding or high tides in the Narragansett Bay area through the year 1956 are given in Tables A-1 and A-2 of Appendix A, Hurricane

Survey, Interim Report, Narragansett Pier, Rhode Island, 15 April 1960. Since 1956 there have been 5 hurricanes and 14 severe storms whose effect on the Narragansett Pier area have been worth recording. The five hurricanes are:

Daisy	--	25	August	1958
Brenda	--	30	July	1960
Donna	--	12	September	1960
Esther	--	21	September	1961
Daisy	--	6-7	October	1962

Hurricane Donna caused moderate tidal flooding, but the other four caused only minor flooding along the Rhode Island coast. A fast moving southwest storm on 30 November 1963, with heavy wave action and winds gusting up to 90 miles per hour, caused moderate tidal flooding along the Rhode Island coast. The other 13 severe storms caused only minor flooding along the Rhode Island coast.

26. FREQUENCY OF TIDAL FLOODING

In the preparation of tidal elevation-frequency data for Narragansett Pier, consideration was given to similar data which had been prepared for Newport Harbor, Rhode Island. The U. S. Coast & Geodetic Survey has maintained a recording tide gage in the Newport Harbor area from September 1930 to the present time. Also there are good high water mark elevation data for the 1938 and August 1954 hurricanes in this area. However, Newport Harbor is located within Narragansett Bay while Narragansett Pier is located on the Atlantic Ocean (Rhode Island Sound). High water mark elevation data indicates that still water tidal flood elevations for the 1938 and August 1954 hurricanes at Narragansett Pier were 3 feet higher than the corresponding elevations at Newport Harbor. The maximum still water tidal elevation which might be expected on an average of once a year at Narragansett Pier is 2.2 feet higher than the corresponding elevation at Newport Harbor. These relatively higher tidal elevations at Narragansett Pier have generally been confirmed by Beach Erosion Board model studies of February 1958 as due to wave setup. The tidal elevation-frequency curve for Narragansett Pier is based on: (a) observed tidal flood elevations for the 1938 and August 1954 hurricanes; (b) Beach Erosion Board model test data of February 1958; and (c) Newport Harbor tidal elevation-frequency data stage related to Narragansett Pier. The Narragansett Pier frequency curve is shown on plate 1-9 and represents a composite curve based on the 329-year period (1635-1963), the 149-year period (1815-1963) that influences the upper portion of the curve, and the 33-year period (1931-1963) for which there is a continuous tide gage record that determines the lower portion of the curve. The plotting positions of the points for the frequency curve were calculated from the following formula:

$$P = \frac{100(M-0.5)}{Y} \quad \text{where}$$

P = percent chance of occurrence in any 1 year
M = number of the event
Y = number of years of record

DESIGN HURRICANE TIDAL FLOOD

27. STANDARD PROJECT HURRICANE

The Standard Project Hurricane (SPH) is representative of the most severe combination of meteorological conditions that are considered reasonably characteristic of the region. The basis for the SPH is a transposition of the September 1944 hurricane. This storm, when located off Cape Hatteras, had the greatest energy of any known hurricane along the Atlantic Coast.

In deriving the standard project hurricane, the 1944 storm was transposed so that it would be entirely over water from the Cape Hatteras area to the New England coast. This change in the track of the storm resulted in less rise in barometric pressure at the center of the storm as it moved northward than was actually experienced in 1944. The transposed hurricane was assumed to advance in a due northerly direction at a forward speed of 40 knots with its center crossing the New England coast at a point 49 nautical miles west of the entrance to Narragansett Bay.

The U. S. Weather Bureau provided a series of wind fields for the transposed hurricane from a position off Cape Hatteras until it dissipated over land. The Texas A & M Research Foundation, in connection with research work conducted by them for the Coastal Engineering Research Center, computed that the transposed hurricane would cause a tidal surge of 11.2 feet at Newport, Rhode Island. The observed 1938 hurricane surge was 8.4 feet. The ratio of these surges (11.2/8.4) gives a response factor of 1.33.

The Standard Project Tidal Flood Surge was obtained by multiplying the observed 1938 hurricane surge by the response factor 1.33. The resulting surge was then added to the appropriate mean spring high water elevation to obtain the tidal flood elevation. This computation is summarized below for Narragansett Pier.

	Narragansett Pier (feet)
Observed 1938 Hurricane Tidal Level, msl (Stillwater)	13.8
Predicted Tidal Stage, msl	2.3
Observed 1938 Hurricane Surge	11.5
Standard Project Surge	15.3
Mean Spring High Water, msl	2.2
Standard Project Flood Elevation, msl (Stillwater)	17.5

28. DESIGN HURRICANE TIDAL FLOOD LEVEL

In lieu of adopting the standard project flood elevation in the design of protective structures for Narragansett Pier, a flood level of 14.0 feet above mean sea level was selected because the higher elevations (a) proved uneconomical; (b) destroyed the scenic view with adverse effect on the recreational aspect of the local economy; (c) made beach access difficult; and (d) were unacceptable to the local interests. The design grade of 14.0 feet above mean sea level closely approximates the maximum stillwater level reached by hurricane floodwaters in a 326-year period.

29. DESIGN WAVE HEIGHTS

Design wave heights at Narragansett Pier were based on wave studies made by the Department of Civil Engineering of the Massachusetts Institute of Technology under a contract with the U. S. Army Engineer Division, New England to investigate certain aspects of the design of a hurricane barrier for the East Passage of

Narragansett Bay, Rhode Island. One of the objectives of the investigation was to determine the size of wind generated waves to be expected to strike the barrier and to select the design wave. Details of this study are presented in Hydrodynamics Laboratory Report No. 66, February 1964, Massachusetts Institute of Technology, titled "Study of Hurricane Barrier for Lower Narragansett Bay."

After investigating both the wave-spectrum method and the significant-wave method of predicting wave heights, it was decided that due to the extensive data on which the significant-wave formulae are based, including some data for high wind velocities, that the significant-wave method would give satisfactory results. The computations of significant wave heights and periods were carried out on an IBM 1620 digital computer using the wind fields of the transposed September 1944 hurricane approaching the Rhode Island coast with a 40-knot forward speed. Plate 1-10 shows the wind field located to produce maximum winds in the Narragansett Pier area.

The design wave heights at Narragansett Pier are based on a significant wave height of 26 feet and a period of 12 seconds. Wave heights at the toe of the protective works have been calculated on the premise that the maximum wave height that can be sustained is 0.78 times the depth of water at the toe. These heights varied from approximately 10 to 20 feet at the toe of the 1 on 9 rock slope in the vicinity of the "Towers" and from 11 to 26 feet at the toe of the 1 on 20 sand slopes (see Table 1-7). The stillwater level used in the design storm was adjusted to reflect the effect of 3 feet of wave setup, increasing the stillwater level from approximately 11 feet msl at a point 800 feet offshore (Model Tests to Determine Wave-Induced Water Level Setups for Average Hydrography Off Narragansett Pier, Rhode Island, Laboratory Memorandum, 7 April 1958, Coastal Engineering Research Center, Washington, D. C.).

30. MAXIMUM WAVE RUNUP AND TOP ELEVATION OF STRUCTURES

Runup values were calculated for numerous locations on the protective structure by the method outlined in "Wave Runup on Composite Slopes," by Thorndike Saville, Jr., Coastal Engineering Research Center, Washington, D. C., using wave heights ranging up to the significant wave height of the design storm. It was determined that the most critical waves were those which break at the toe of the structure (where $H_b = 0.78 d_b$). It was assumed that the runup on rock slopes would be reduced 50 percent because of the roughness factor. A reduction of 20 percent was made in the runup over the 100-foot smooth sand berm and a reduction of 40 percent was made in the runup over the 100-foot rock berm.

The maximum wave runup values are summarized in Table 1-7. The selected hurricane protection plan is shown on plate 1-1 and typical sections are shown on plate 1-2. The structures consist of composite slopes and concrete walls with top elevation of 16.5 feet above msl.

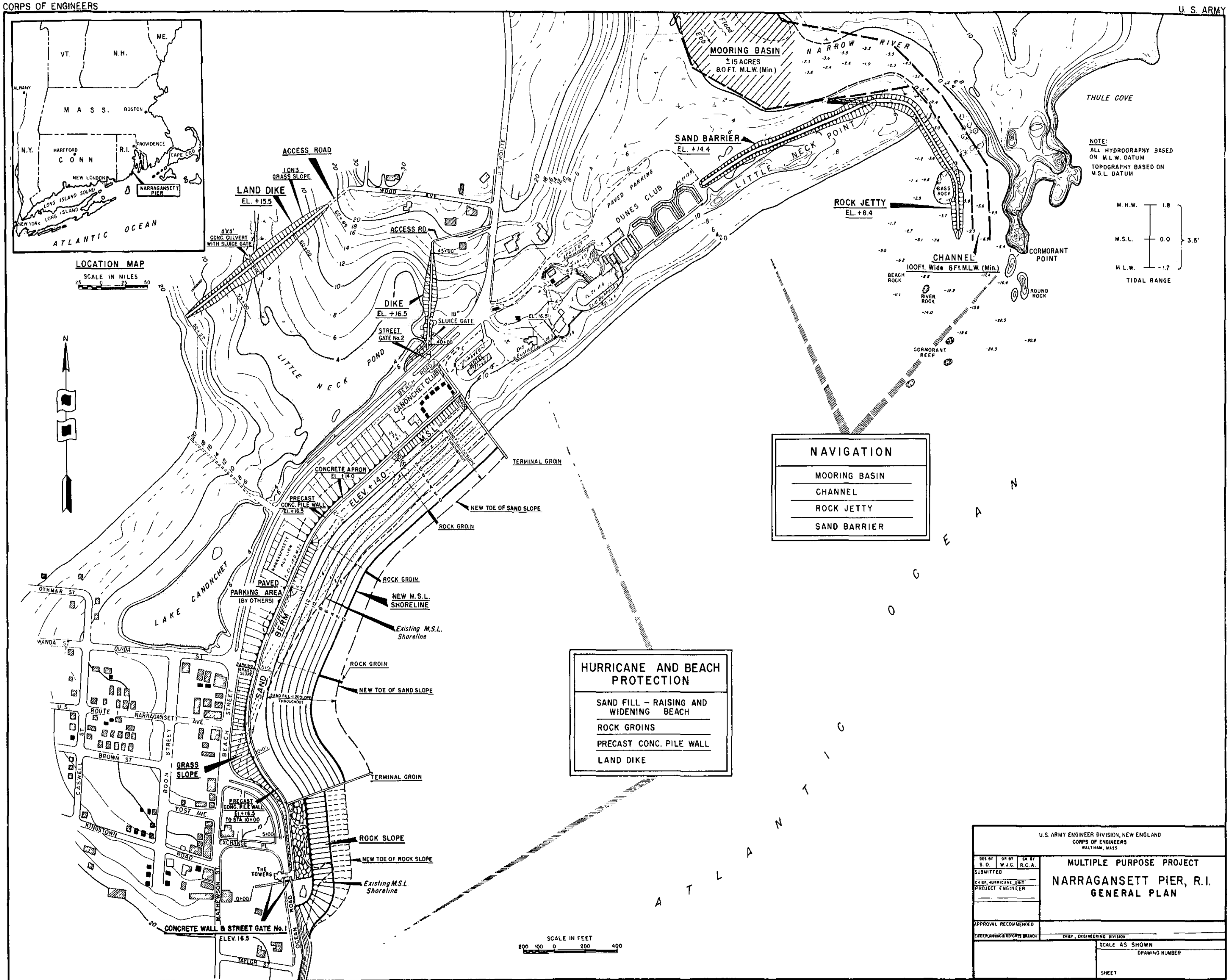
TABLE 1-7

MAXIMUM WAVE RUNUP AND TOP ELEVATION OF STRUCTURES

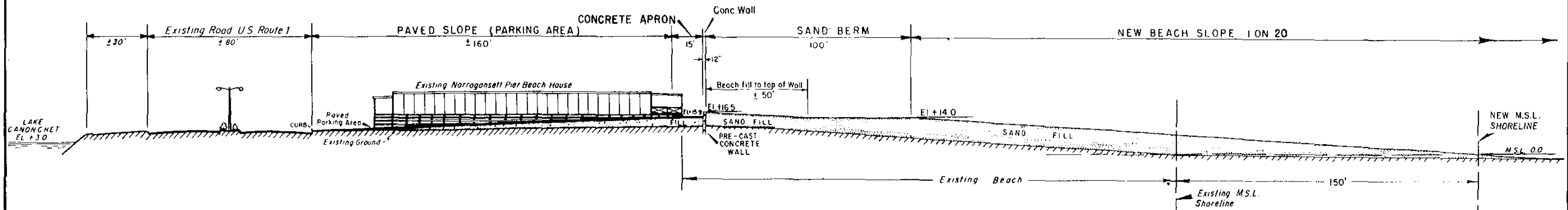
Location	Elevation: Top (feet, msl)	Elevation: Ground at Toe (Ave.) (feet, msl)	Design Water Surface at Toe (feet, msl)	Maximum Wave Height at Toe (feet)	Maximum Runup: Height (feet)	Maximum Runup: Elevation (feet, msl)
Station 3+50	16.5	0.0	12.8	10.0	2.3	15.1
Station 7+00	16.5	-14.9	12.2	21.2	3.3	15.5
Station 8+00	16.5	-22.5	10.8	26.0	5.2	16.0
Station 24+00	16.5	- 1.0	12.7	10.7	2.5	15.2
Station 25+50	16.5	- 8.0	12.5	16.0	3.8	16.3

NOTE: Stations 3+50 and 7+00 are similar to Station 4+00 as shown on plate 1-2

Stations 8+00, 24+00 and 25+50 are similar to Station 12+00 as shown on plate 1-2

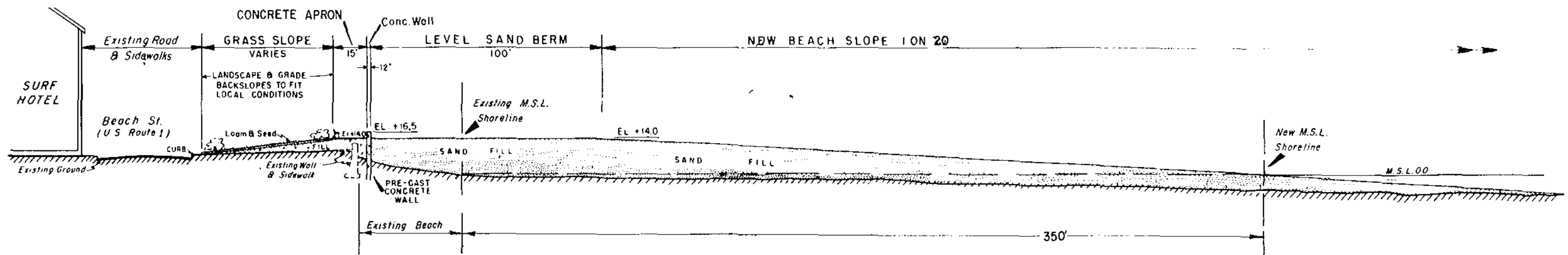


LOCATION MAP
SCALE IN MILES
VT.
N.H.
ME.
MASS.
BOSTON
N.Y.
CONN
R.I.
PROVIDENCE
HARTFORD
NEW LONDON
CAPE COD
LONG ISLAND SOUND
LONG ISLAND
NEW YORK
NARRAGANSETT PIER
ATLANTIC OCEAN
ACCESS ROAD
LONG GRASS SLOPE
LAND DIKE
EL. +15.5
5'X5' CONC. CULVERT WITH SLUICE GATE
ACCESS RD.
DIKE
EL. +16.5
18" SLUICE GATE
STREET GATE No. 2
LITTLE NECK POND
CANONCHET CLUB
CONCRETE APRON
EL. +14.0
PRECAST CONC. PILE WALL
EL +16.5
ELEV +14.0
M.S.L.
TERMINAL GROIN
NEW TOE OF SAND SLOPE
ROCK GROIN
NEW M.S.L. SHORELINE
Existing M.S.L. Shoreline
PAVED PARKING AREA (BY OTHERS)
BERM
SAND
LAKE CANONCHET
OTHMAR ST.
WANDA ST
OUIDA ST
U.S. ROUTE 1
NARRAGANSETT AVE
BROWN ST
CASWELL ST
BOON STREET
BEACH STREET
GRASS SLOPE
YOST AVE
KINGSTOWN ROAD
EXCHANGE PL
PRECAST CONC. PILE WALL EL+16.5 TO STA. 10+00
ROCK SLOPE
NEW TOE OF ROCK SLOPE
THE TOWERS
OCEAN ROAD
CONCRETE WALL & STREET GATE No. 1
ELEV. 16.5
TAYLOR ST
MOORING BASIN
± 15 ACRES
8.0 FT. M.L.W. (Min.)
NARROW RIVER
SAND BARRIER
EL. +14.4
LITTLE NECK POINT
PAVED PARKING
DUNES CLUB
ROCK JETTY
EL. +8.4
BASS ROCK
CHANNEL
100 Ft. Wide 8 Ft. M.L.W. (Min.)
BEACH ROCK
RIVER ROCK
CORMORANT POINT
ROUND ROCK
CORMORANT REEF
THULE COVE
NOTE:
ALL HYDROGRAPHY BASED ON M.L.W. DATUM
TOPOGRAPHY BASED ON M.S.L. DATUM
M.H.W. 1.8
M.S.L. 0.0
M.L.W. -1.7
3.5'
TIDAL RANGE
NAVIGATION
MOORING BASIN
CHANNEL
ROCK JETTY
SAND BARRIER
HURRICANE AND BEACH PROTECTION
SAND FILL – RAISING AND WIDENING BEACH
ROCK GROINS
PRECAST CONC. PILE WALL
LAND DIKE
ATLANTIC OCEAN
SCALE IN FEET
200 100 0 200 400
U.S. ARMY ENGINEER DIVISION, NEW ENGLAND
CORPS OF ENGINEERS
WALTHAM, MASS
MULTIPLE PURPOSE PROJECT
NARRAGANSETT PIER, R.I.
GENERAL PLAN
SCALE AS SHOWN



PROFILE SECTION AT STATION 20+00

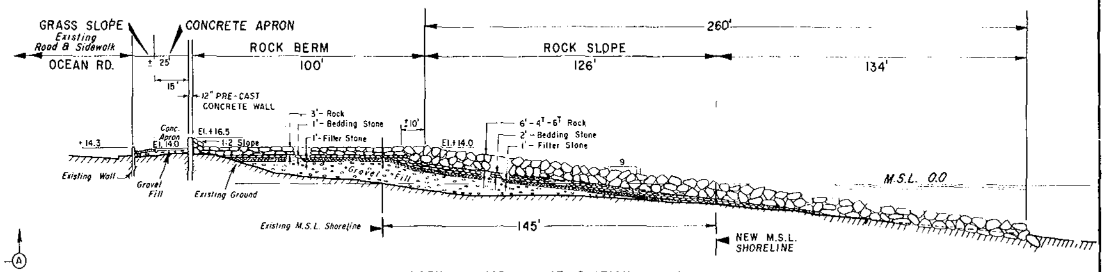
SCALE IN FEET (VERT. & HORIZ.) 20 10 0 20 40



TYPICAL PROFILE SECTION

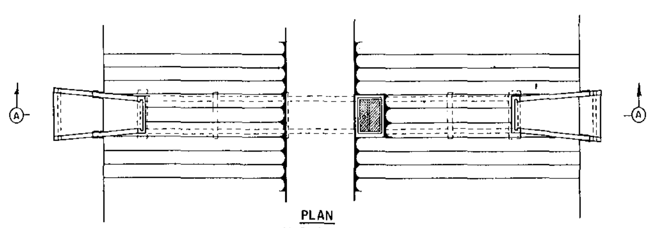
LOCATED APPROXIMATELY OPPOSITE NARRAGANSETT AVENUE (STA. 12+00)

SCALE IN FEET (VERT. & HORIZ.) 20 10 0 20 40



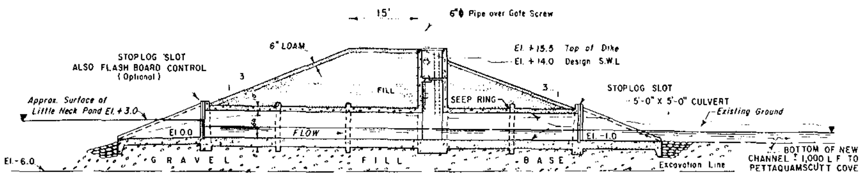
PROFILE SECTION AT STATION 4+00

SCALE IN FEET (VERT. & HORIZ.) 20 10 0 20 40



PLAN

SCALE IN FEET 10 5 0 10 20



SECTION A-A THRU DIKE & CULVERT

SCALE IN FEET 10 5 0 10 20

U.S. ARMY ENGINEER DIVISION, NEW ENGLAND
CORPS OF ENGINEERS
WALTHAM, MASS.

MULTIPLE PURPOSE PROJECT

NARRAGANSETT PIER, R.I.

SECTIONS

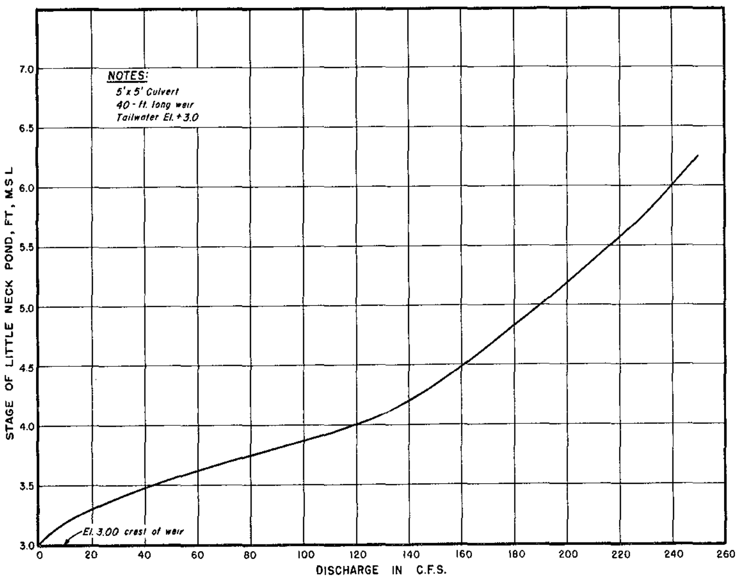
APPROVED: [signature]
CHIEF, ENGINEERING DIVISION

DATE

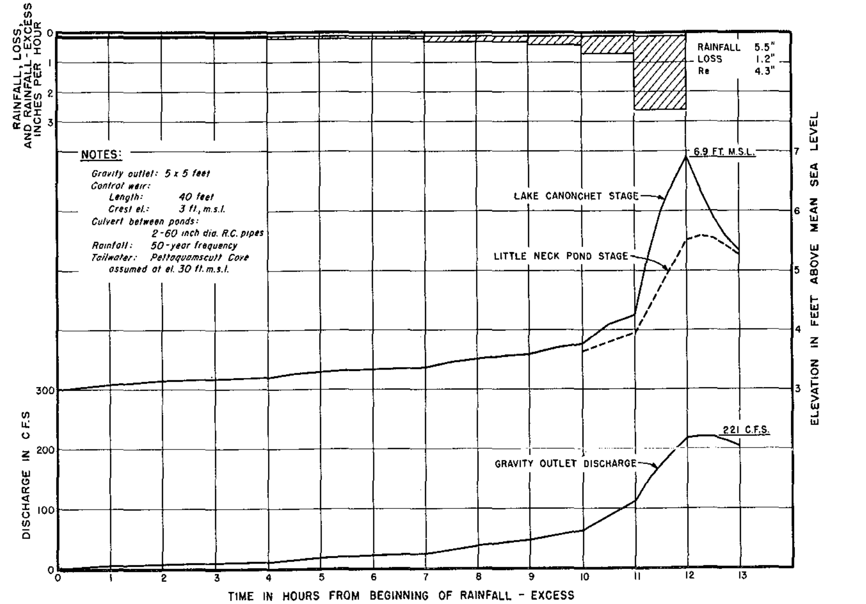
SCALE AS SHOWN

DRAWING NUMBER

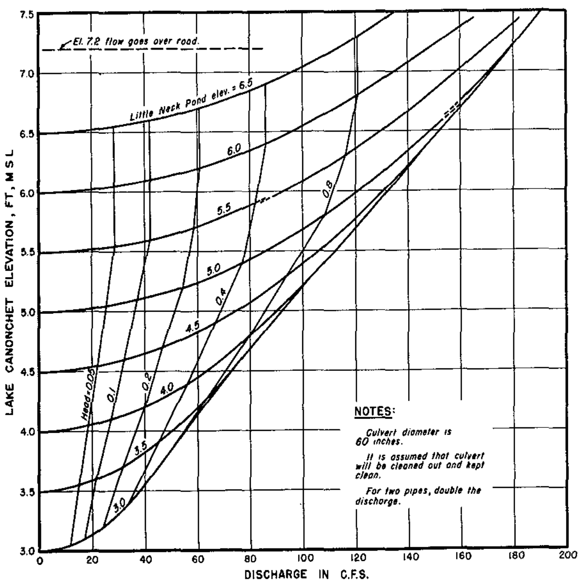
SHEET OF



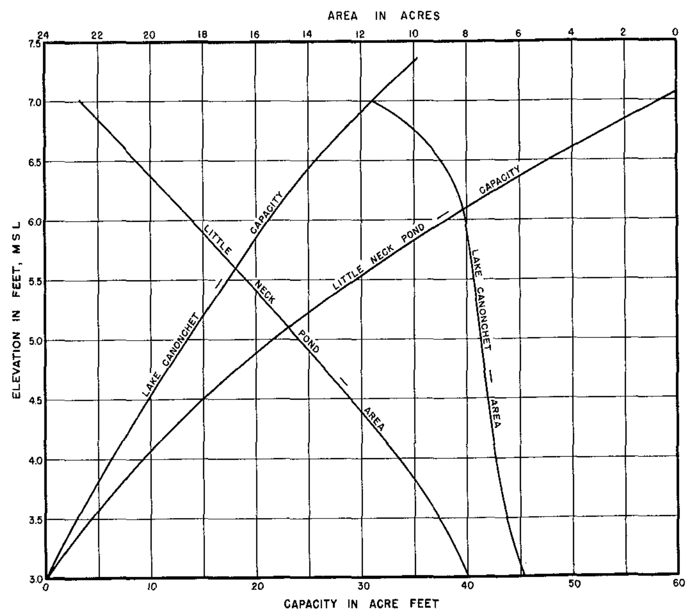
RATING CURVE OF GRAVITY OUTLET



ROUTING TO TEST GRAVITY OUTLET



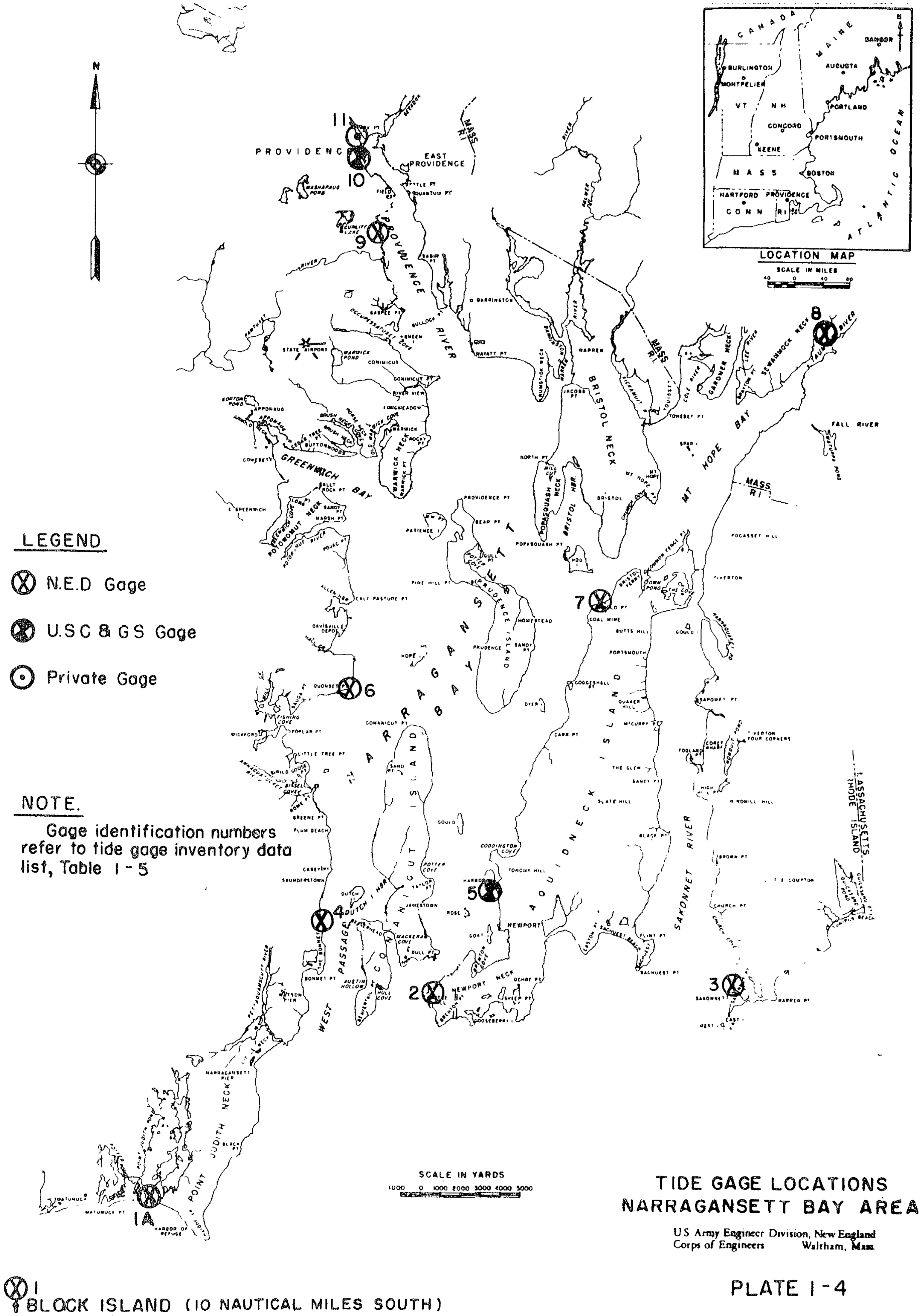
RATING CURVE OF CULVERT BETWEEN PONDS



MULTIPLE PURPOSE PROJECT
NARRAGANSETT PIER, R.I.

INTERIOR DRAINAGE

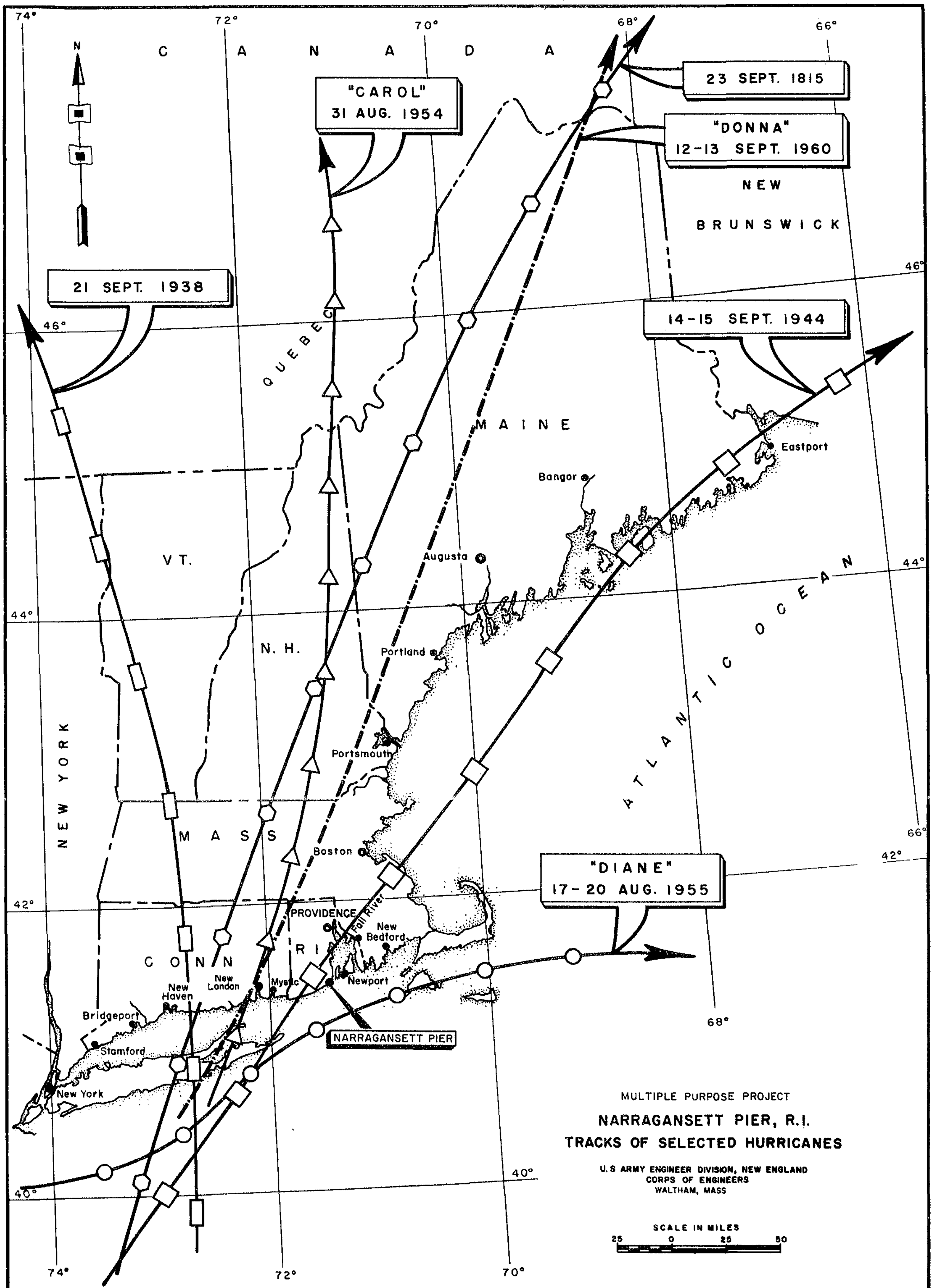
U.S. ARMY ENGINEER DIVISION, NEW ENGLAND
CORPS OF ENGINEERS WALTHAM, MASS.



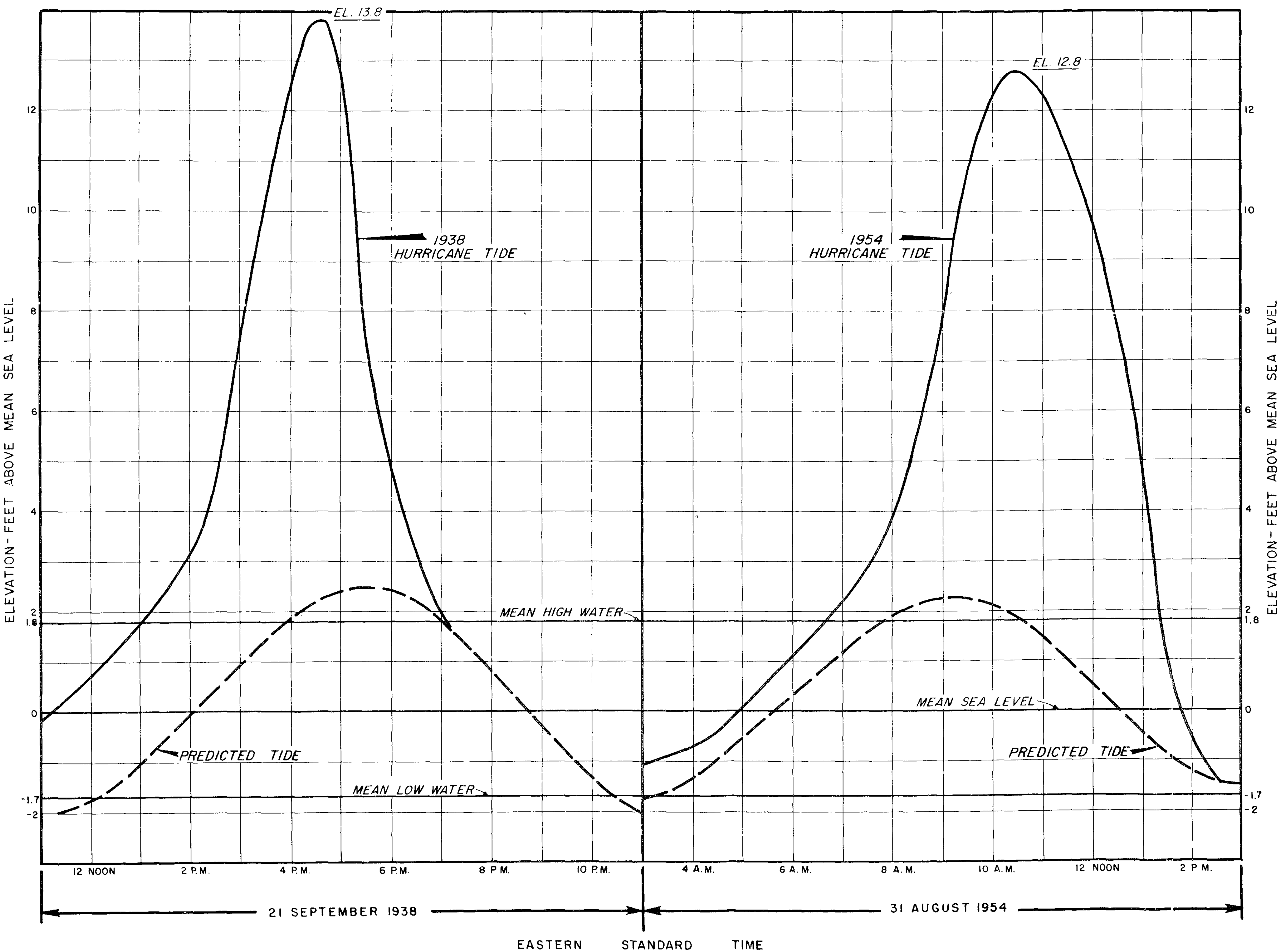
TIDE GAGE LOCATIONS
NARRAGANSETT BAY AREA

U S Army Engineer Division, New England
Corps of Engineers Waltham, Mass.

PLATE 1-4



CANADA
"CAROL"
31 AUG. 1954
23 SEPT. 1815
"DONNA"
12-13 SEPT. 1960
NEW
BRUNSWICK
21 SEPT. 1938
14-15 SEPT. 1944
QUEBEC
MAINE
Eastport
Bangor
Augusta
VT.
N. H.
Portland
NEW YORK
Portsmouth
ATLANTIC OCEAN
MASS
Boston
"DIANE"
17-20 AUG. 1955
PROVIDENCE
Fall River
New Bedford
CONN
RI
Newport
Mystic
New London
New Haven
Bridgeport
Stamford
New York
NARRAGANSETT PIER
MULTIPLE PURPOSE PROJECT
NARRAGANSETT PIER, R.I.
TRACKS OF SELECTED HURRICANES
U.S ARMY ENGINEER DIVISION, NEW ENGLAND
CORPS OF ENGINEERS
WALTHAM, MASS
SCALE IN MILES
25 0 25 50
74°
72°
70°
68°
66°
46°
44°
42°
40°

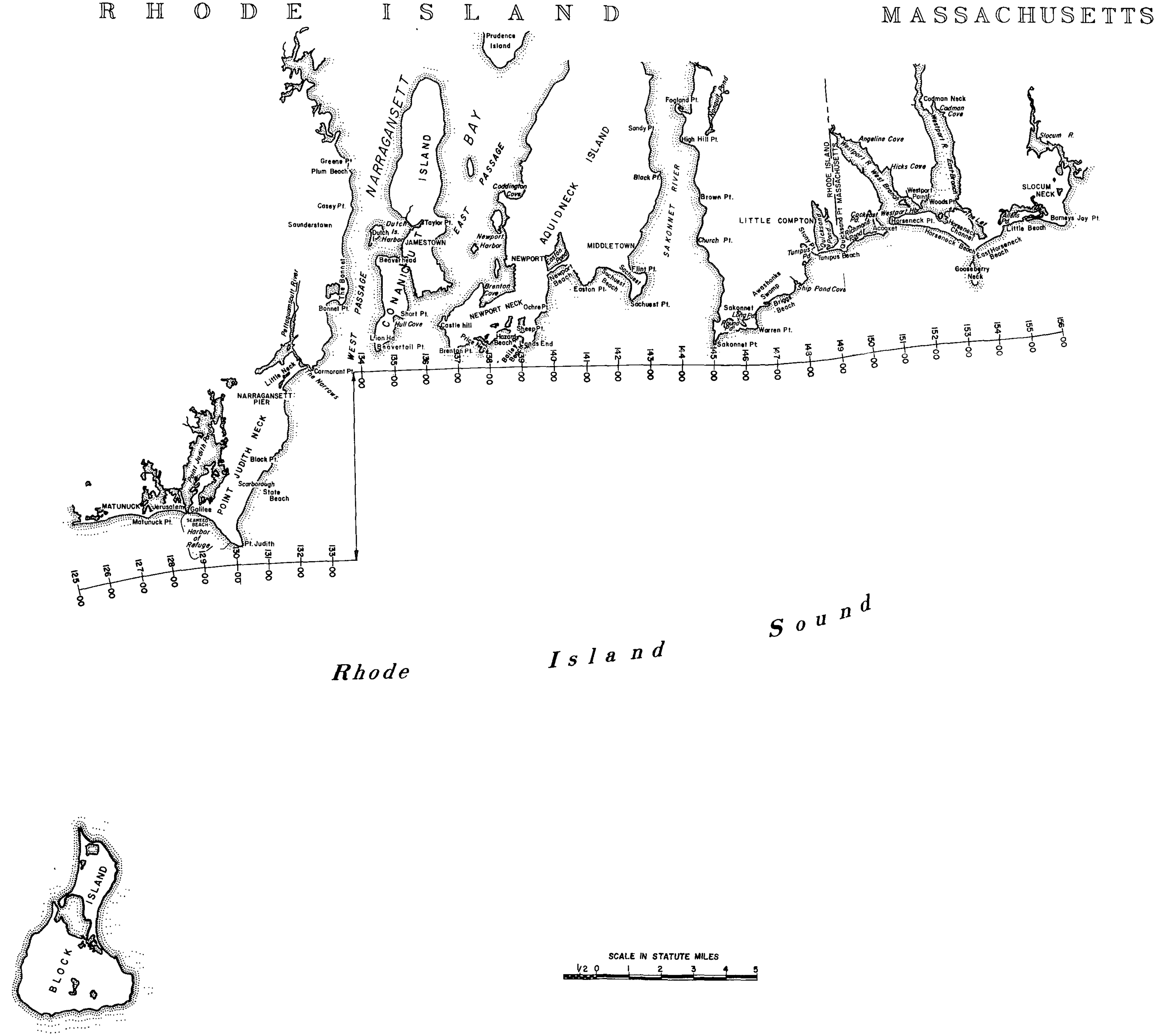


MULTIPLE PURPOSE PROJECT

NARRAGANSETT PIER, R. I.
TIDE CURVES
HURRICANES OF 1938 & 1954

U.S. Army Engineer Division, New England
Corps of Engineers Waltham, Mass.

PLATE I-6



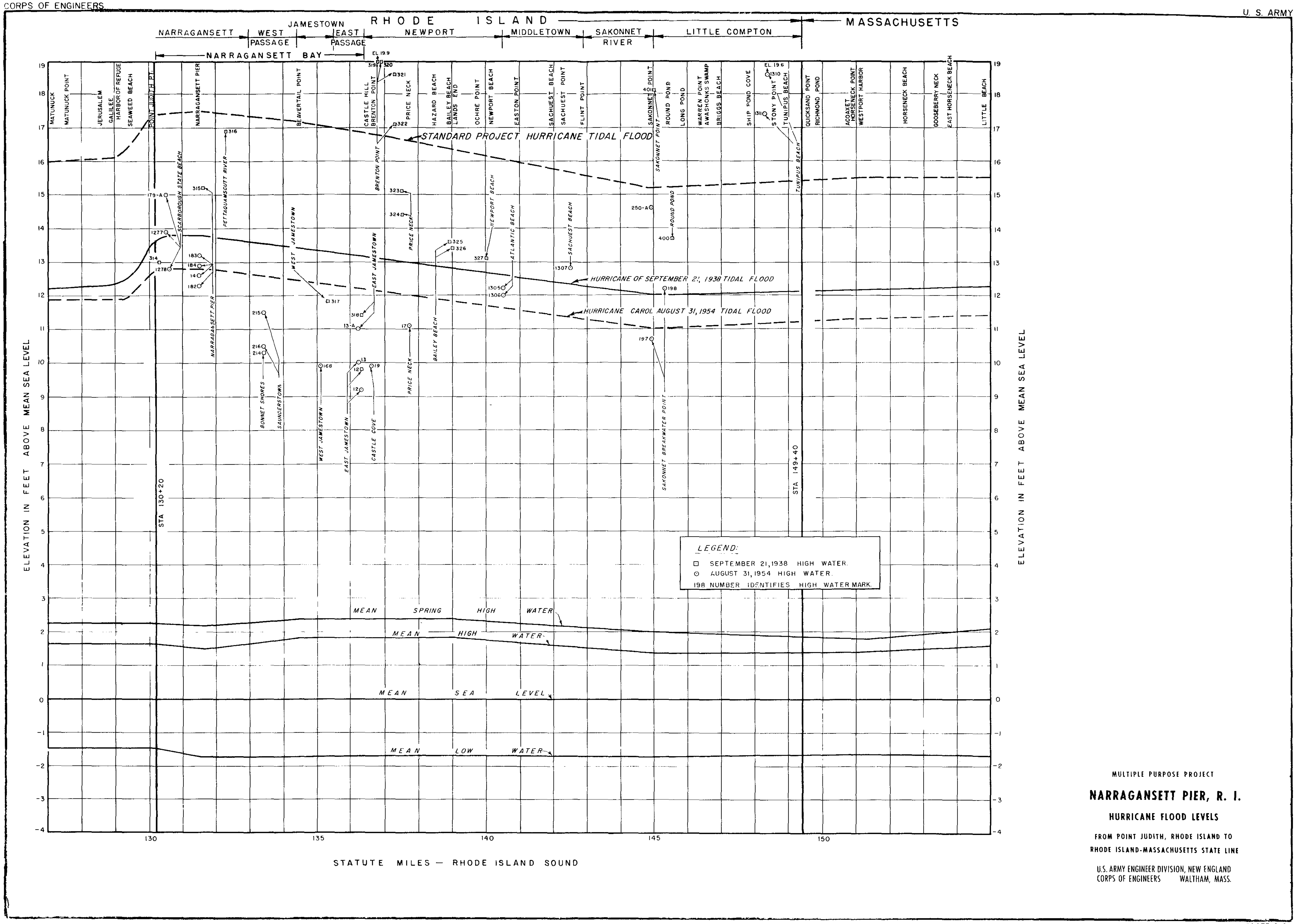
MULTIPLE PURPOSE PROJECT

NARRAGANSETT PIER, R. I.

LOCATION MAP FOR HURRICANE FLOOD LEVELS

FROM POINT JUDITH, RHODE ISLAND TO RHODE ISLAND-MASSACHUSETTS STATE LINE

U.S. ARMY ENGINEER DIVISION, NEW ENGLAND
CORPS OF ENGINEERS WALTHAM, MASS.



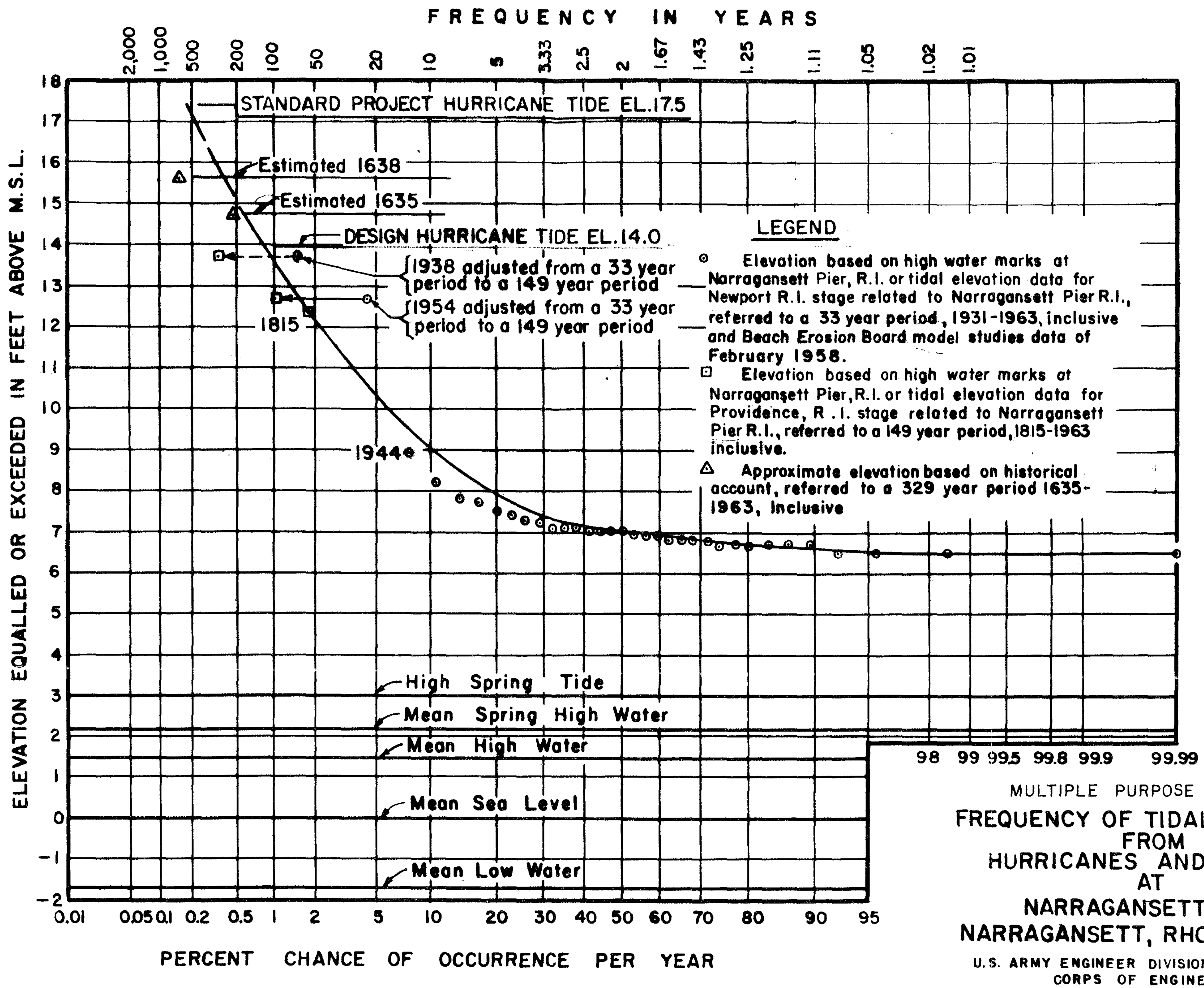
MULTIPLE PURPOSE PROJECT

NARRAGANSETT PIER, R. I.

HURRICANE FLOOD LEVELS

FROM POINT JUDITH, RHODE ISLAND TO RHODE ISLAND-MASSACHUSETTS STATE LINE

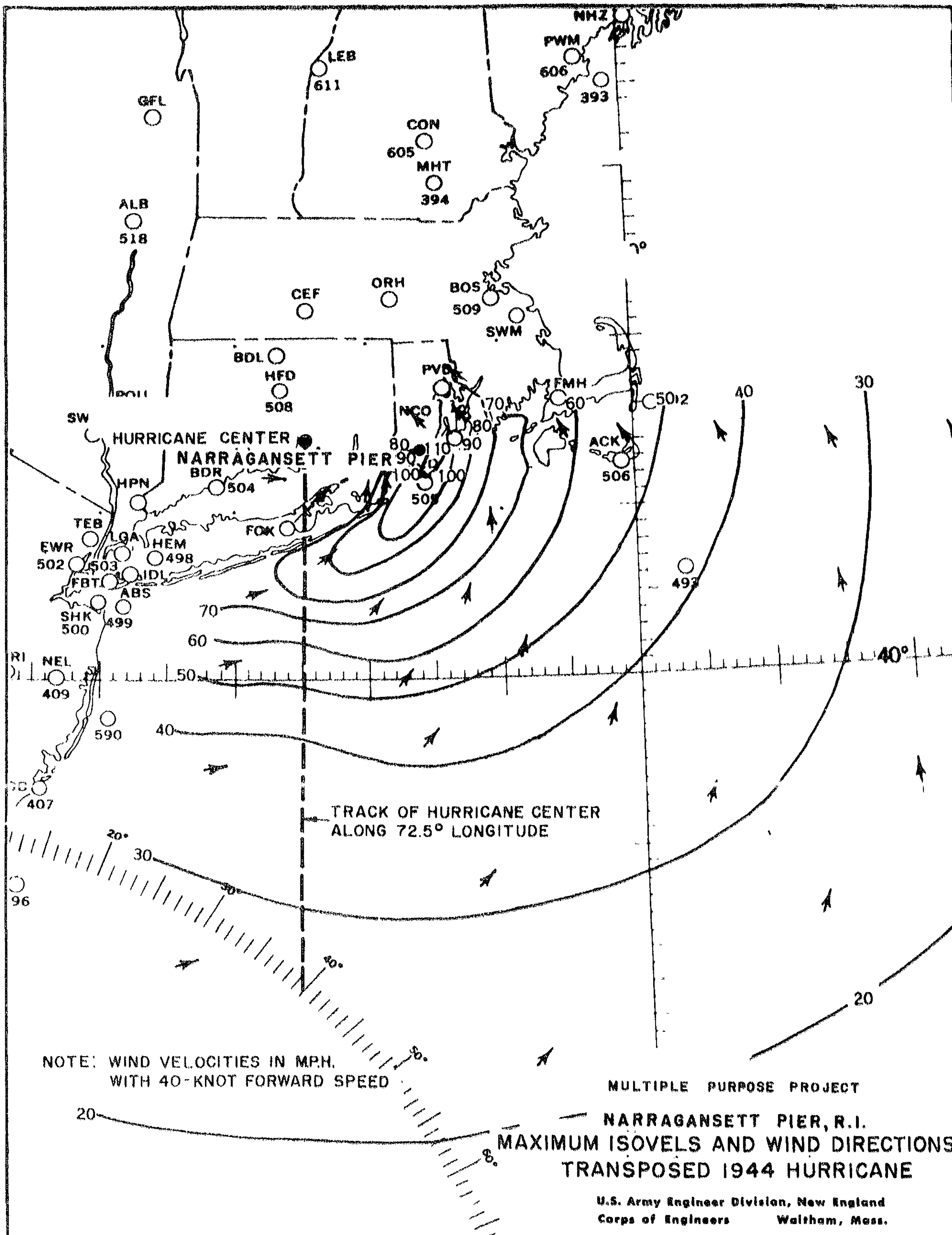
U.S. ARMY ENGINEER DIVISION, NEW ENGLAND
CORPS OF ENGINEERS WALTHAM, MASS.



MULTIPLE PURPOSE PROJECT

FREQUENCY OF TIDAL FLOODING FROM HURRICANES AND STORMS AT NARRAGANSETT PIER NARRAGANSETT, RHODE ISLAND

U.S. ARMY ENGINEER DIVISION, NEW ENGLAND
CORPS OF ENGINEERS
WALTHAM, MASS. SEPTEMBER 1965



MULTIPLE PURPOSE PROJECT

NARRAGANSETT PIER, R.I.

MAXIMUM ISOVELS AND WIND DIRECTIONS

TRANSPOSED 1944 HURRICANE

U.S. Army Engineer Division, New England
Corps of Engineers Waltham, Mass.

U.S WEATHER BUREAU DATA